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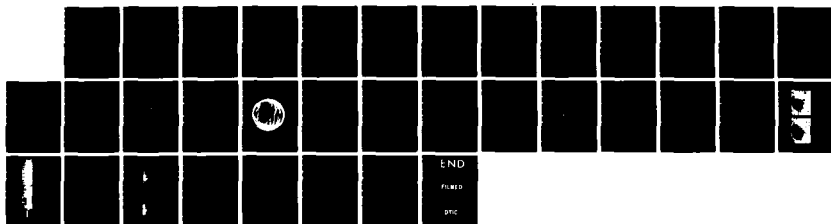
THE DYNAMICS OF EQUATORIAL F LAYER IRREGULARITIES(U)
BOSTON UNIV MA DEPT OF ASTRONOMY J AARONS ET AL.
30 JUN 85 ACBU-6276-5 N00014-82-K-0235

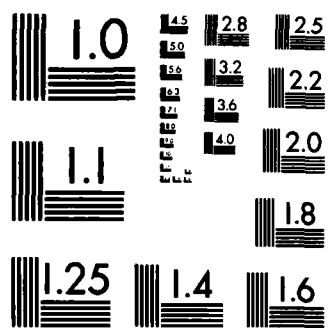
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FINAL REPORT

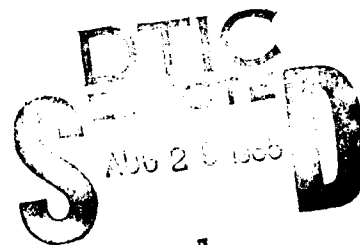
Covering the period: March 1, 1982-June 30, 1985

THE DYNAMICS OF EQUATORIAL F LAYER IRREGULARITIES

Jules Aarons and Michael Mendillo, Co-Principal Investigators

Department of Astronomy
Boston University
Boston, MA 02215

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I. RESEARCH OBJECTIVES

The objective of this research contract was to study the dynamics of the development and decay processes of F layer irregularities at the magnetic equator and in the high electron density regions near the equator using optical and radio observations. We utilized the observations of a campaign on Ascension Island in January, 1981, to assist in understanding the evolution of irregularity activity in the anomaly region of the magnetic equator. We used the optical images obtained in a later campaign in Natal, Brazil in September, 1982, to compare observations with simulation studies carried out at the Naval Research Laboratory.

II. INTRODUCTION TO EQUATORIAL IRREGULARITIES

Ionospheric irregularities generated by various natural instability mechanisms produce amplitude, phase and angular fluctuations on signals traversing the ionosphere. The effects vary with frequency, time of day, magnetic and solar activity, season, and latitude. The global picture of severe scintillation activity on signals from 20 MHz to 4 GHz indicates two principal regions of practical and theoretical importance i.e. the high latitude region comprising the polar, auroral, and plasmapause areas and the equatorial region. The most intense irregularities exist at equatorial latitudes.

- * Aarons, J. (1984) Equatorial Trans-Ionospheric Propagation Conditions Affecting Digital Communications, AGARD Conference Proceedings on Propagation Influences on Digital Transmission Systems #363, AGARD, Paris, France.

At the magnetic equator, the physical picture is that after sunset irregularities develop at 250-300 km heights, form large scale bubbles or plumes or patches (names given to this cluster of irregularities). These patches of irregularities rise through the ionosphere. The patch, after development, has the form of a banana with its long axis magnetic north-south. A conceptual picture of the extent of the patch is given in Figure 1 where we have pictured the lines of force of the earth's field as viewed from Ascension Island, one of the two campaigns analyzed in detail. This site is in the anomaly region where electron density is very high after sunset during years of high solar flux. Within the patch are the small scale irregularities of 1 km which produce the radio fading of satellite transmissions. At distances away from the magnetic equator the lines of force of the earth's field appear at different altitudes. In the illustration, an irregularity at 1000 km located above the magnetic equator will appear at 625 km when viewed along a radio path from Ascension Island. Irregularities on the magnetic equator below 600 km are not observed in the F layer from Ascension Island.

Irregularity intensity is a function of dip latitude. Since the equatorial region comprises two differing areas of irregularity intensity the field programs took place at two sites, one near the magnetic equator (Natal) and the other on Ascension Island in the anomaly region of the equator.

The anomaly regions, north and south of the magnetic equator, are the areas of high electron density particularly during years of solar maximum. Ascension Island at a dip latitude of 16 degrees, located in the equatorial anomaly, was a perfect site for the high solar flux year of 1981. Optical data at 6300 Å indicated the depletion regions, radio observations (from 136 MHz to 4 GHz) allowed for an understanding of several radio phenomena.

Natal, Brazil, close to the magnetic equator, was an excellent site for observations of phenomena for the region within 5 degrees of the magnetic equator. Optical measurements at 6300 Å and 7774 Å were supplemented by observations at 137 MHz and 250 MHz of the weaker equatorial scintillations. Polarimeter measurements of the total electron content were also made during this time. Figure 2 shows the geometry of the observations including both geographic and geomagnetic grids.

The aim of the contract was to produce theoretical and empirical models of development of F layer irregularities at equatorial latitudes through coordinated optical and radio observations. The concept was to study the dynamics of the development and decay processes through observations. The data base was to be the combined optical and radio measurements taken during intensive campaigns in the equatorial region. The models to be developed were to be empirical models using available data as well as semi-empirical models, utilizing observations and theoretical studies. In addition a comparison was to be made between the models and the simulation studies of NRL.

We utilized the observations of the campaign on Ascension Island in January, 1981, to assist in developing empirical models of scintillation activity in the equatorial region. We used the optical images obtained in a later campaign in Natal, Brazil in September, 1982, to compare observations with simulation studies carried out at the Naval Research Laboratory. Both data sets consist of depletion images and radio frequency records at frequencies varying from 137 MHz to microwaves.

A. ASCENSION ISLAND OBSERVATIONS AND ANALYSIS

An all-sky airglow imaging system was used to make the first ground based study of large scale plasma depletion regions in the equatorial ionosphere. One 6300 A optical image from Ascension Island is shown in Figure 3; the darkened areas show regions of depletion of electron density in the patches observed in the Ascension Island campaign. These depletion regions or patches are the seats of small scale irregularities which produce scintillation and severe HF fading. With the depletion images shown (darkened areas are the depletions of electron density in the normal air glow pattern) a grid was developed (Figure 4) with the patch outlines transferred to a height above the equator. The tilts of the patches were then measured as a function of altitude over the equator and as function of time. The final result was a measurement of the tilt of the patch towards the west as time progresses through the night. Figure 5 shows the results of the extensive analysis of the data with increasing westward tilts of the patches as the night progresses. For the first time quantitative values of the westward tilts of the patches were outlined.

By mapping the airglow depletion features along the geomagnetic field lines to the equatorial plane, the characteristics of plasma depletion regions were described including shears and bifurcation patterns as well as tilts.

* Mendillo, M., and A. Tyler (1983) The geometry of depleted plasma regions in the equatorial ionosphere, J. Geophys. Res., 88, 5778.

With these images it is possible to note when a particular patch will cross the propagation path to a satellite since the predominant motion is eastward. The path from Ascension Island to the MARISAT satellite is shown in Figure 1 (intersection at 350 km). During the Ascension campaign the technique was used to forecast patch motion across a radio propagation path. The radio and optical observations indicate that there is a gap between patches that can be utilized for trouble free transmission.

Simultaneous radio observations at 136 MHz to 7 GHz studied the F region irregularities embedded in the depletions that produce intense scintillation of satellite signals. The first search for the parameters of the small scale irregularities was to determine the geometrical form of these irregularities. If the irregularities were vertical sheets the maximum intensity would be noted when the ray path was along the sheet as shown in Figure 6. Vertical sheets, conceived theoretically from upwelling plasma bubbles, were ruled out. Multiplying factors were developed for horizontal sheets such as given in Figure 7. Neither model served well and elongated rods emerged as the best fit for the form of the small scale irregularities.

* Aarons, J., J.A. Klobuchar, H.E. Whitney, J. Austen, A.L. Johnson, C.L.Rino (1983) Gigahertz scintillations associated with equatorial patches, Radio Sci., 18, 421-434.

By comparing optical images and radio frequency observations taken in the Ascension Island campaign of January, 1981, as illustrated in Figure 8, there were differences found in the time between the western wall of one patch and the eastern wall of a following patch. It was possible from data such as this to determine the effective electron density thickness of the F layer producing UHF and gigahertz scintillations. For microwaves, the thickness found in the limited number of samples available was of the order of 70 kilometers; the 250 MHz scintillations were affected by a thickness of the irregularity layer of approximately 150 km.

- * Aarons, J. (1985) The Form and Effects of Equatorial F Layer Irregularity Patches at Anomaly Latitudes; accepted for publication in J. Atmos. and Terr. Sciences.

B. EMPIRICAL MODEL TO FORECAST MEAN SCINTILLATION AT 250 MHZ ALONG MAGNETIC EQUATOR: FUNCTION OF DAY OF YEAR, SOLAR FLUX, TIME OF DAY AND MAGNETIC INDEX

In order to provide a means of forecasting when scintillation activity will maximize, an empirical formula was developed from available long term equatorial measurements of satellite transmissions at 250 MHz. The formula, developed only for the region near the magnetic equator, yields mean fading as a function of solar flux, time of day, and day of the year and geomagnetic activity. Figure 9 illustrates the output available from the formula. To assist users of the empirical model of scintillation activity, multiplying factors were given to aid in the model's use at frequencies above 250 MHz and at latitudes other than the magnetic equator.

The limitations of this model of scintillation activity were clearly outlined with multiplying factors given if the path is in the anomaly region of high electron density and if the satellite frequencies are in L Band. These limitations became apparent during the empirical model development when it was found that an adequate electron density model to express the densities at the magnetic equator and the anomaly region at wide ranges of solar flux has yet to be developed.

Near the end of the contractual period the formula was examined in light of a new model of electron density in the equatorial region (both at the magnetic equator and at magnetic anomaly latitudes). The new model being developed in part at Boston University was of importance in sorting out the great range of difference of scintillation activity at latitudes 20 degrees from the magnetic equator compared to those within 5 degrees of the magnetic equator. Use of the semi-empirical model aided in evaluating the question as to why there was a considerable decrease in scintillation activity after 2200 local time. A large portion of the decrease is due to the decrease of electron density as the night progresses relative to the high electron density at 2000-2200 local time in this region, a decrease modelled realistically by the new model. The results of this study in determining the effective thickness of the irregularity region will be of help in developing scintillation models to forecast and predict disturbances in the entire equatorial region. It may be possible in the future, with a knowledge of electron density profiles, to determine scintillation levels at anomaly latitudes from a knowledge of the perturbation at the magnetic equator.

- * Aarons, J., (1984) Modelling Equatorial Scintillation for System Use, Proceedings of the Ionospheric Effects Symposium Office of Naval Research, Washington, D.C.
- * Aarons, J. (1985) Construction of a Model of Equatorial Scintillation Intensity, Radio Science, 20, 397-402.

C. MAGNETIC BAY AND TRIGGERING OF IRREGULARITY PATCHES

In a study of scintillation observations at two equatorial observatories the dynamics of plume generation as they effect scintillation have been determined under conditions of a deep magnetic bay; it has been found that the rise and subsequent fall of the F layer in the post-midnight period produces new plumes, some of which may move westward across trans-ionospheric paths. During a severe magnetic disturbance a change from the normally downward drift of the F region (and a westward electric field) is reversed to produce an upward rapid vertical drift. At certain levels of magnetic activity in the post-midnight time period, irregularity patches are generated with the sole trigger being the lifting of the F region; the impact of this for the generation of the post sunset patches is of importance since triggers were not needed. Corroborating evidence from other storms and other observatories was found. Figure 10 illustrates an example of a simple post-midnight triggering of a patch of irregularities.

* Aarons, J. and A. DasGupta (1984) Equatorial Scintillations during the Major Magnetic Storm of April 1981, Radio Science, 19, 731-739.

D. PATCH WALLS

During the second year of the contract optical and radio data were utilized to understand the distinctive effects of the walls of the patch on scintillation. The walls are the regions of steepest gradient of electron density. The earlier observations of Ascension Island in the anomaly region of the equator were supplemented by additional data taken in a campaign by Mendillo and Baumgardner as well as others in Natal, Brazil (near the magnetic equator) and by observations of satellite beacon signals made by Goodman and Martin from the USNS Hayes. Modelling of both the quiet equatorial ionosphere and the F region irregularities started. New optical equipment was developed to allow for digital information to be used for immediate viewing and for data analysis.

Recent studies of the development of the equatorial irregularity patches have been concerned with the high intensity along the walls of the patches. In a study of the scintillations of a large series of measurements of patches it was found that in general the irregularity intensity was continuous across the patch but at the walls the tilt and the observing geometry must be factored into the model to determine the effect on trans-ionospheric signals. The conception of some authors that intense scintillation activity would be observed only along the patch walls was not borne out by the observational material which included studies near the magnetic equator made by Goodman and Martin, the campaign at Natal as well as observations in the Appleton equatorial anomaly region.

Using the geometry of the patch, its tilt as a function of time, and its dimensions, it is possible to minimize the effect of fading. Combining the statistics of scintillation occurrence and levels with the geometry as determined primarily by depletion methods, it is possible to formulate a model of the 50-200 km East West patches to utilize periods of low fading. In a paper presented at the Ionospheric Effects Symposium, a model of scintillation occurrence was combined with the geometry of the walls to illustrate methods of minimizing scintillation effects. Scintillation indices are plotted from Ascension Island data in Figure 11 and show scintillation levels at walls at anomaly latitudes are not greater than those within the patch.

- * Aarons, J. (1984) Scintillation Effects of Equatorial Plume Walls
Proceedings of the Seventh International Symposium on
Equatorial Aeronomy, University of Hong Kong.
- * Aarons, J. (1985) The Form and Effects of Equatorial F layer
Irregularity Patches at Anomaly Latitudes; accepted for
publication in J. Atmos. and Terr. Sciences.

E. NATAL OBSERVATIONS AND ANALYSIS

Using the combined activities of specialists in rocket instrumentation and a large array of ground observations of optical emissions and of satellite beacon signals, it was possible to obtain a large series of measurements of the irregularity structures that exist in the region around the magnetic equator. The Ascension Island campaign centered on the anomaly region during a year of high solar flux.

Natal, Brazil, with its site close to the magnetic equator presented an opportunity to obtain depletion measurements at a series of wavelengths and to compare the optical measurements with total electron content and scintillation as developed from the radio data. The optical measurements were taken at 7774 Å and 6300 Å and the radio measurements were taken at 137 MHz and 250 MHz. All sky imager data was taken along with a narrow beam (one degree) photometer record.

Effort was devoted to detailed case studies of the days when radio scintillation and depletion images were observed simultaneously in September, 1982. The study concentrated on determining the relationships between the increased levels of 6300 Å on the walls of the developing bubble and irregularity patterns obtained at 136 MHz and 250 MHz. The aim was to study the differences between observations on the magnetic equator and in the anomaly region.

The imager records are illustrated in Figure 12. Since these are digitally obtained the data analysis proceeds from the data tapes. The image yields a total view of the sky pattern in the wavelength observed. The narrow beam photometer was used for detailed analysis of the depletions and enhancements on the walls of the patches.

Figure 13 illustrates the data set at 137 MHz during the passage of a patch of irregularities through the SIRIO satellite radio propagation path. One can see first the depletion of the total electron content; the depletion is closely followed in time by the intense scintillation activity at 137 MHz. The scintillation reached saturation (increase of signal to maximum level which is approximately 10 dB above the mean and fade to noise level). The data on Sept 12-13, 1982 is illustrative of the high level of UHF scintillations during a period when the patch or depletion at 300 km still maintains a unique integrity. In Figure 13 the two patches move through the propagation path with clear depletions showing. The scintillations at 137 MHz are saturated. The difference between observations at the equator and in the anomaly region is that frequently between patches in the equatorial region there are irregularities of moderate or low intensity. Thus meter wavelength beacon scintillations appear even between the patches at equatorial latitudes.

The photometer data reveals similarly the existence of two distinct patches. The 7774 A reduced data from the photometer as shown in Figure 14 indicates a depletion existed; essentially the 7774 A observations indicate total electron content. The 6300 A data indicate only weakly the two patches. The scintillation activity however fails to show indications of the gap between the two depletions indicating irregularities still existed between the two patches. On the FLTSAT records at 250 MHz saturated scintillations were noted during the time period 2210-2225.

In the anomaly region as shown in Figure 15 from Goodman and Martin (1982) there are periods of time between patches with low scintillation intensity. The reason for the difference is that the low intensity irregularities are centered at low altitudes near the magnetic equator. When the low altitude irregularities are projected along the lines of force of the earth's field (see Figure 1) they do not appear in the F layer at great distances from the magnetic equator.

F. SIMULATION/VERIFICATION

The study of the geometry patterns of equatorial plasma depletions, using our Ascension Island all-sky 6300 Å airglow imaging data, was completed and published in the Journal of Geophysical Research. The vertical profiles of eastward F region plasma drifts, derived from these data, were of direct relevance to the NRL model studies of instability processes that govern the evolution of equatorial bubbles and plumes. The results of this work show how monochromatic imaging and/or scanning photometric results at different wavelengths can be used to investigate the detailed relationship between the NRL simulations, observational possibilities and actual frames of data. Theoretical plasma instability models (developed at NRL) for the generation of equatorial plasma depletions as shown in Figure 16 have been used to predict the airglow signatures associated with the evolving perturbations (bottom frames). Tracking the instability process by all-sky airglow imaging at the equator was demonstrated during the field campaign in Natal, Brazil.

Computer simulation studies conducted by Zalesak, Ossakow, and colleagues at NRL described the vertical and horizontal characteristics of the F layer irregularities that produce fading in the equatorial ionosphere. These theoretical characteristics were compared to optical images obtained in Natal, Brazil, in September, 1982. The walls of the bubbles of irregularities showed enhancements at 6300 Å while reductions were seen at 7774 Å. As shown in Figure 17 7774 Å airglow emissions profiles are similar to those obtained by electron density measurements and therefore are closely related to total electron content measurements. 6300 Å emissions come from a relatively narrow range of altitudes in the F layer. The 7774 Å depletions observed in the Natal campaign are ascribed to a reduction in the plasma content of flux tubes spanning the equator, as shown in the simulation results. The enhancements appear to be associated with the downward motions of plasma on both sides of the upwelling bubbles, as shown in the NRL simulations. Airglow imaging data obtained in the campaign in Natal, Brazil, confirm the simulation results, indicating that the formation and early-time behavior of ionospheric depletions can be studied by their airglow signatures observed from ground-based equatorial sites. Tracking the instability process by all-sky airglow imaging at the equator was demonstrated during this field campaign in Natal, Brazil.

A capability was developed in-house to relate the east versus west wall characteristics of the depletions, derived via image processing methods, to the true geometrical plasma gradients in the lower F-region and the NRL spread-F code simulations. The results of this work show how monochromatic imaging and/or scanning photometric results at different wavelengths can be used to investigate the detailed relationship between the NRL simulations, observational possibilities and actual frames of data.

- * Mendillo, M. (1984) Airglow Patterns Associated with Plasma Instability Simulations of Equatorial Irregularities, Proceedings of the Seventh International Symposium on Equatorial Aeronomy, University of Hong Kong.
- * Mendillo, M., H. Spence, and S.T. Zalesak (1985) Airglow Signatures from Plasma Instability Model of Equatorial Plasma Depletions; accepted for publication in J. Atmos. and Terr. Sciences.

IV. CONCLUSIONS

Basic studies in equatorial aeronomy include the following:

- a. Electric field
- b. Modeling of the equatorial ionosphere
- c. Plasma instabilities in the electrojet
- d. Plasma instabilities in the F region
- e. Middle atmosphere studies
- f. Special topics

Several areas showed considerable advances in the last several years. In the area of modelling of the quiet ionosphere, the values of various models more closely approached observed values than earlier; the models used in normal communications forecasting were low by a factor of two and more. The dynamics of the production of F layer irregularities were approached by a new concept of E layer turbulence being the source of the upwelling and plume leading to F layer instabilities. In addition more work was done to indicate that electric field changes produced during strong magnetic activity were sufficient to trigger F layer plumes.

The principal question in F layer dynamics that is unresolved is the source or trigger of quiet period plumes that produce deep fading on radio signals. Rocket experiments (Condor) failed to reveal any new information on the triggering mechanism for the plume. No study was offered to reveal the cause of the day to day variations of the equatorial F layer irregularities. While there are papers which purport to link the origin of the patch with lower altitude parameters no one-to-one experiment or series of observations has even attempted to determine the necessary and sufficient conditions for the origin of patches of irregularities.

Our principal program was to study the dynamics of F layer irregularity development and decay. It is at F layer heights that communications over long distance are achieved and it is at F layer heights that irregularities produce serious effects of trans-ionospheric and reflected HF transmissions.

The study made several conclusions of interest among which are the following:

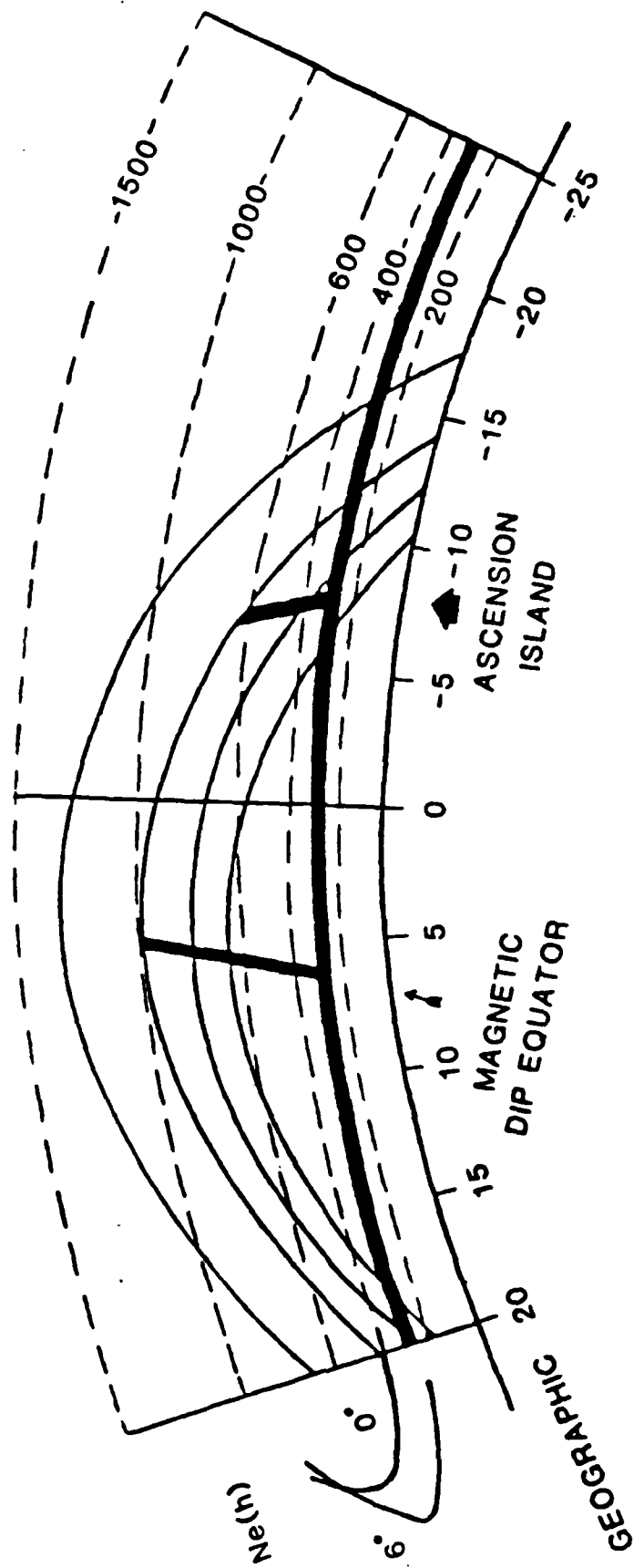
- a. Equatorial small scale irregularities are probably rods.
- b. Scintillations at anomaly latitudes do not show maxima at the walls or edges of the patches or depletion regions.
- c. Depletion photographs plus geometry considerations show the extent of the patches (important in modelling and forecasting).
- d. 6300 A depletion can be projected to conjugate point so that interhemispheric effects can be predicted.

Topics which remain to be addressed in equatorial aeronomy in future years include the physics of coupling between the solar wind and the equatorial ionosphere and lower atmosphere, more emphasis on middle altitude dynamics and coupling mechanisms, and a program to determine triggering mechanisms for the patch and the causes of day to day variability at F layer heights.

Perhaps the most interesting area will be to study the linking of magnetospheric and auroral parameters with equatorial effects. The Interplanetary Magnetic Field in particular seems to give promise as a forecasting tool for some equatorial parameters. A study of the physics involved will have to reveal the linkage mechanism probably via the ring current.

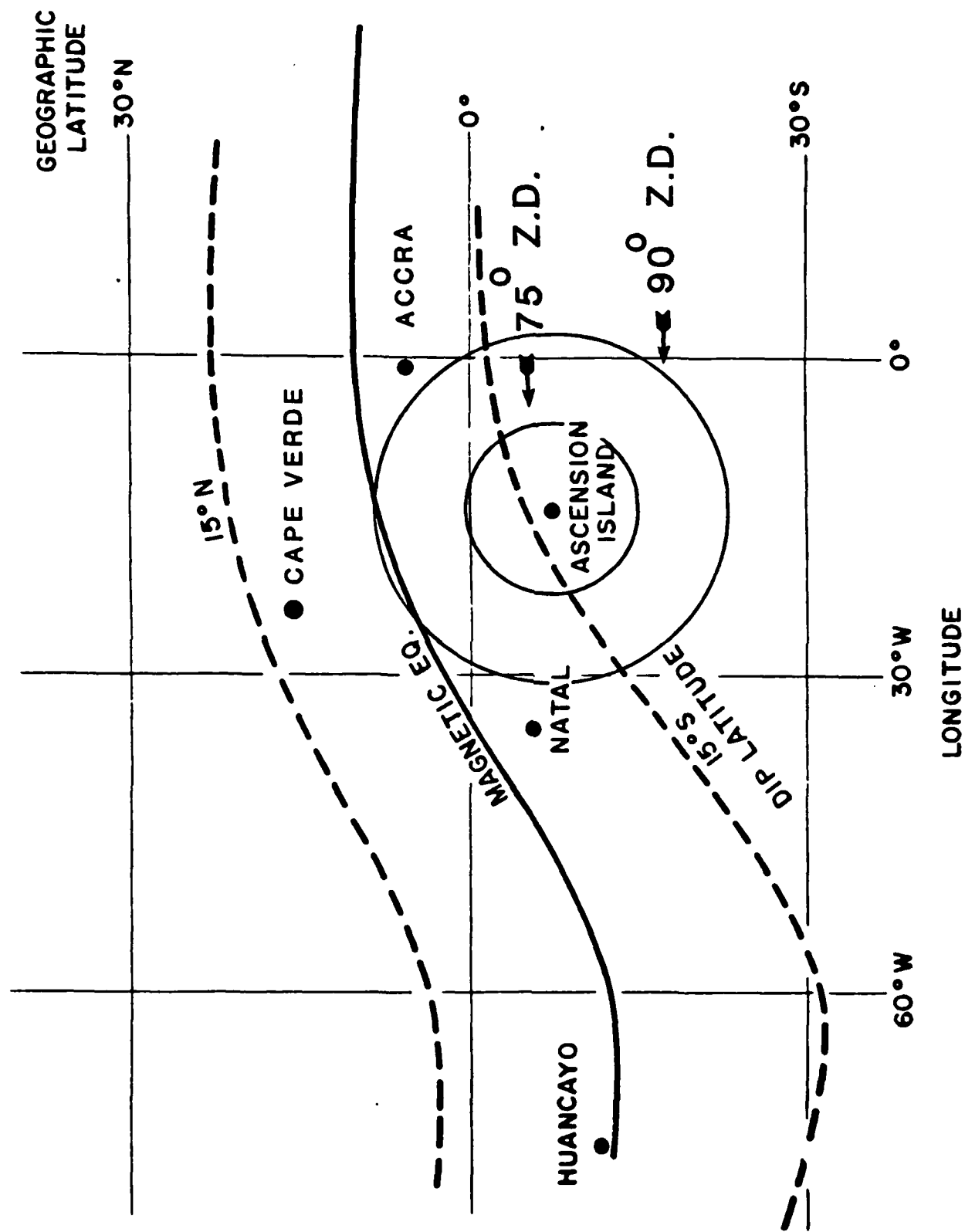
V. FUTURE STUDIES

Techniques developed by Boston University for the coordinated optical and radio measurements and analytical techniques will be brought to bear on high latitude irregularity dynamics. In the years of low solar activity (1985-1987) there will be unique opportunities to study the effect of magnetic storms in isolation at plasmopause, sub-auroral and auroral latitudes. We expect to add incoherent scatter to our observations and to study the dynamics of blobs or patches of irregularities producing scintillation on satellite signals and clutter on HF OTH radar. Sub-auroral, plasmopause and auroral latitudes will be studied.



CROSS SECTION OF EQUATORIAL REGION WITH
PROPAGATION PATHS TO SATELLITES SHOWN

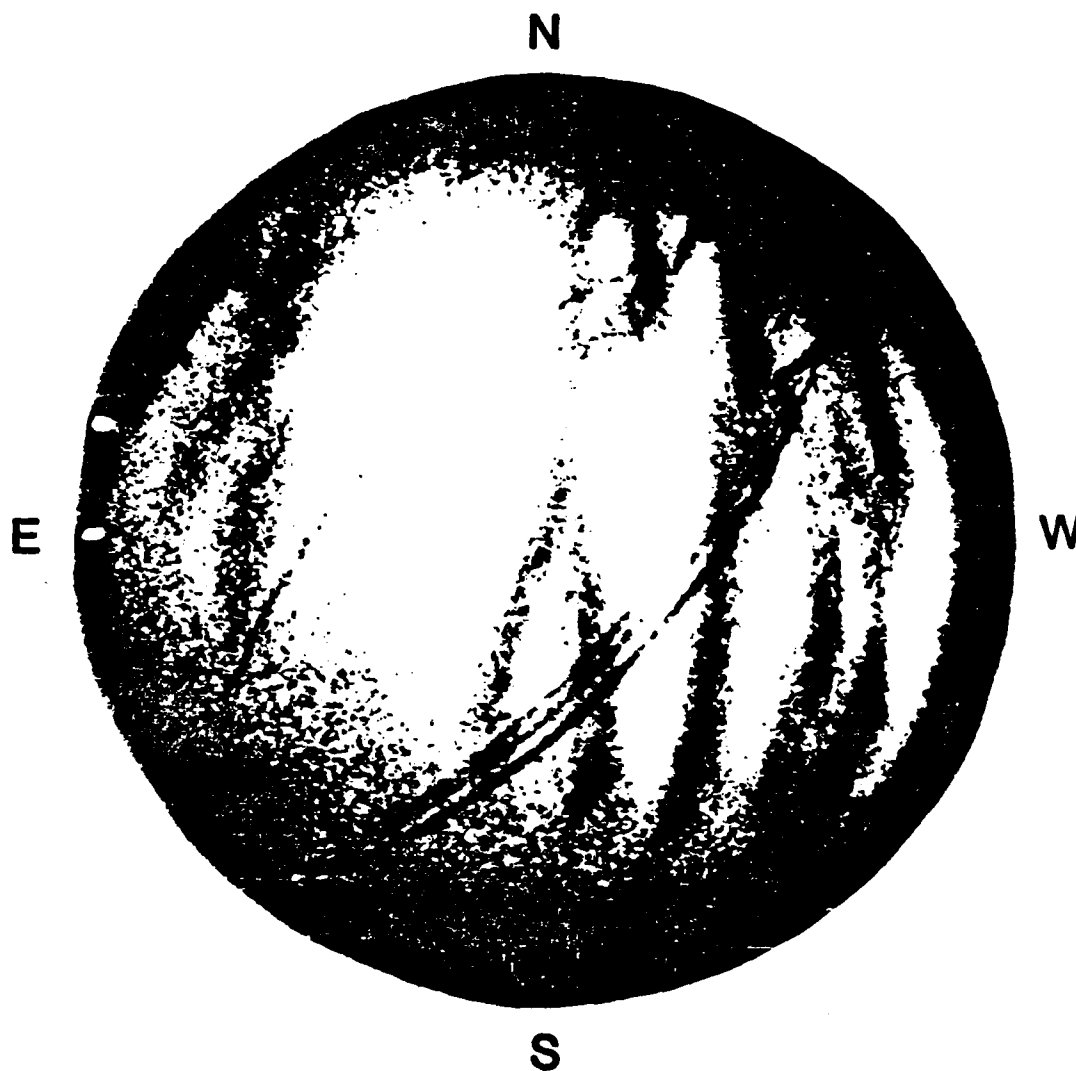
FIGURE 1



GEOGRAPHIC AND DIP LATITUDE CONTOURS
OF FIELD SITES: NATAL AND ASCENSION

FIGURE 2

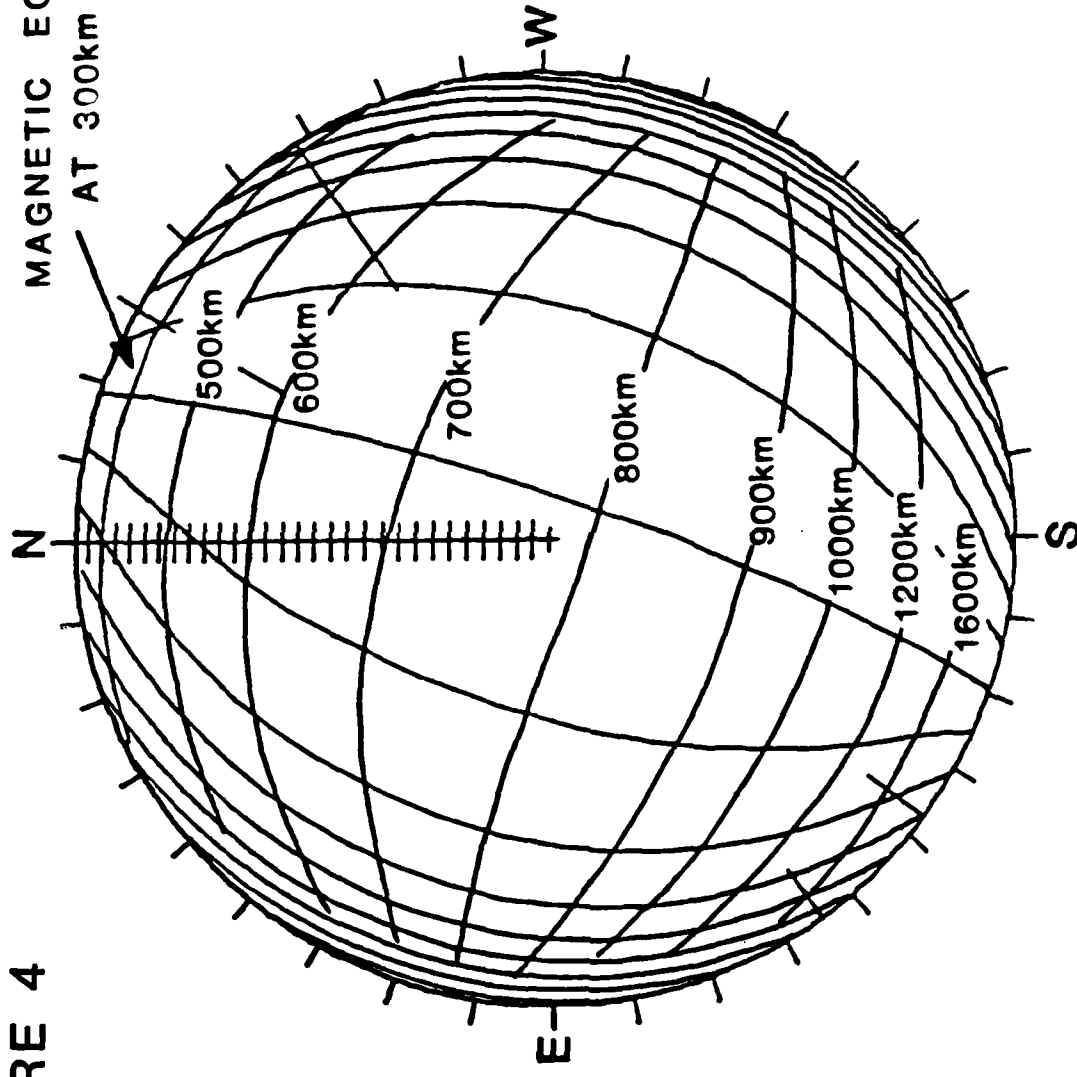
FIGURE 3



PATCH STRUCTURE AS NOTED
FROM ASCENSION ISLAND.

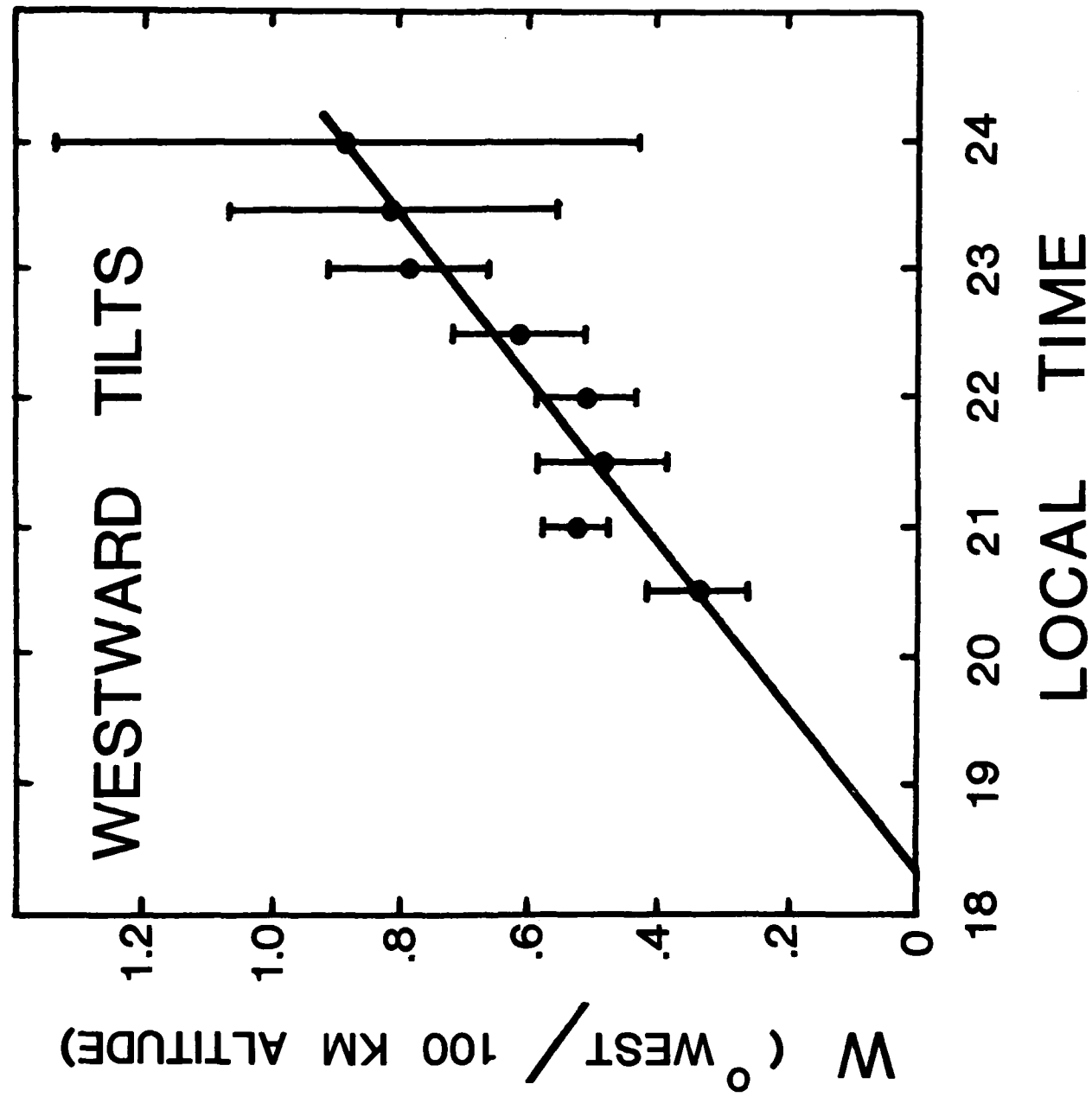
DARK REGIONS ARE DEPLETIONS
OF ELECTRON DENSITY (PATCHES).

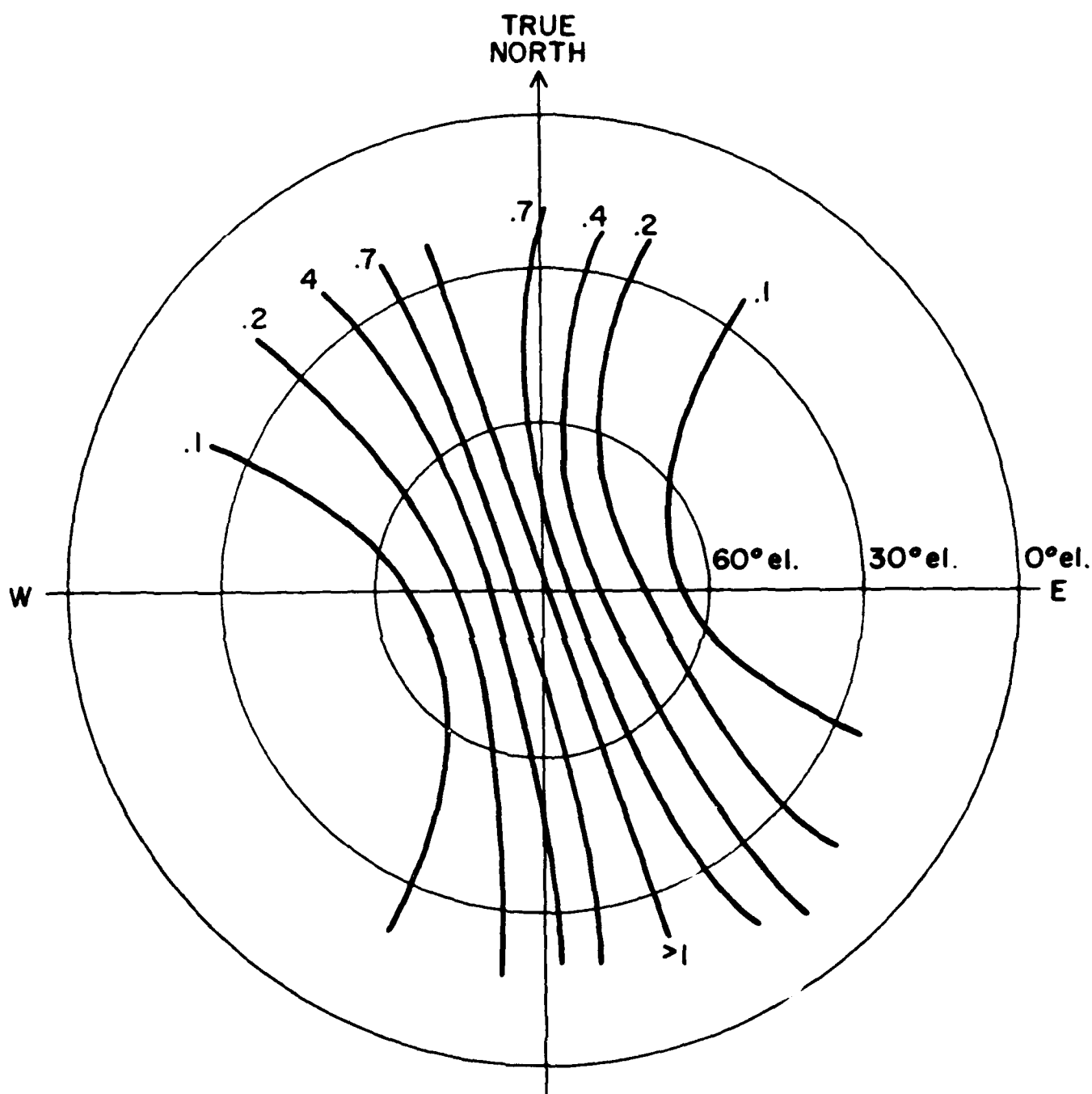
FIGURE 4



MAGNETIC MERIDIANS AND
HEIGHT ABOVE MAGNETIC EQUATOR

FIGURE 5

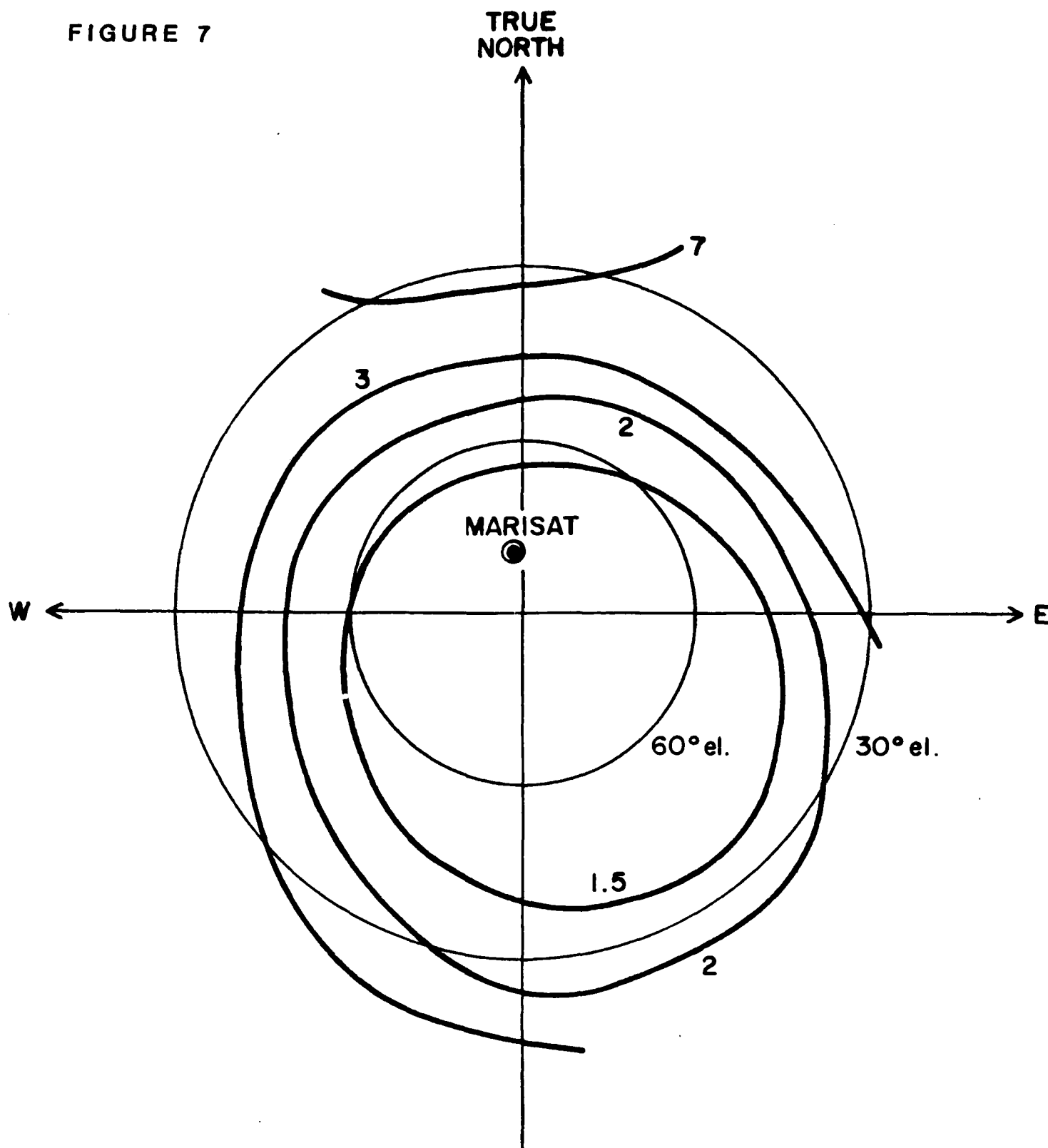




MULTIPLYING EFFECTS OF VERTICAL SHEETS (10:1:10)
AT ASCENSION ISLAND

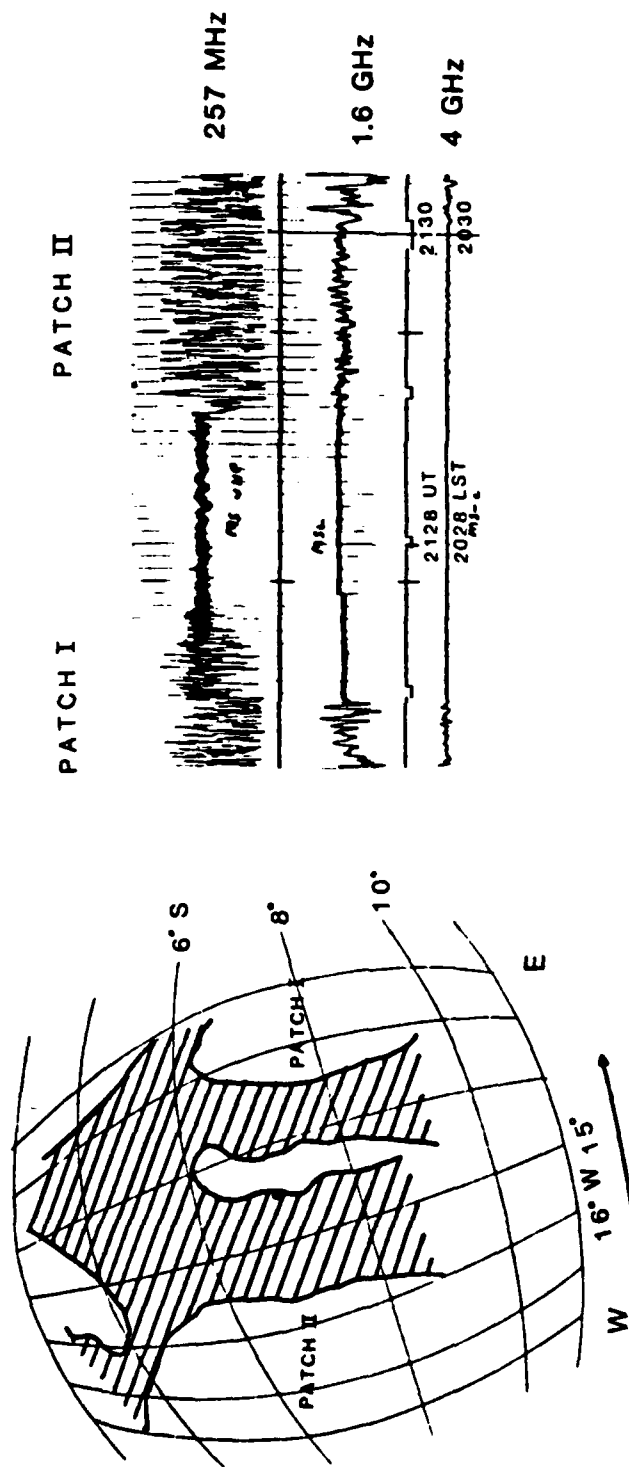
FIGURE 6

FIGURE 7



MULTIPLYING EFFECT OF FIELD ALIGNED HORIZONTAL
SHEETS 1:5:10 ON S_4 INDICES
AT ASCENSION ISLAND

COORDINATED OPTICAL AND RADIO CAMPAIGNS

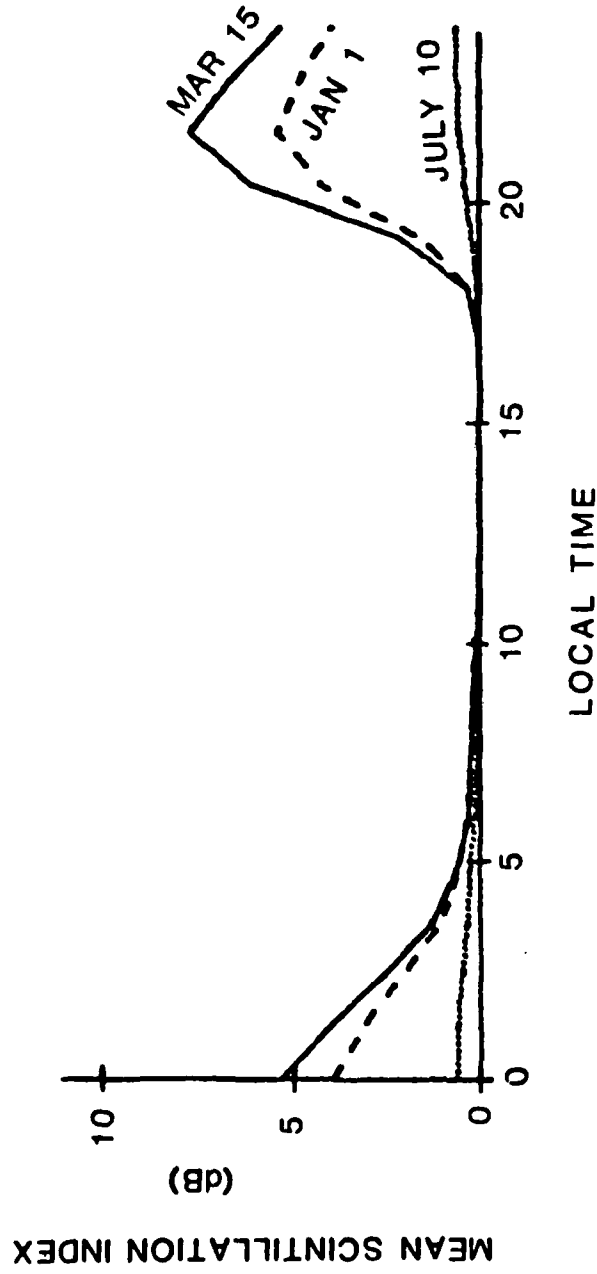


FADING MARISAT

TRACING OF DEPLETION
IMAGE

FIGURE 8

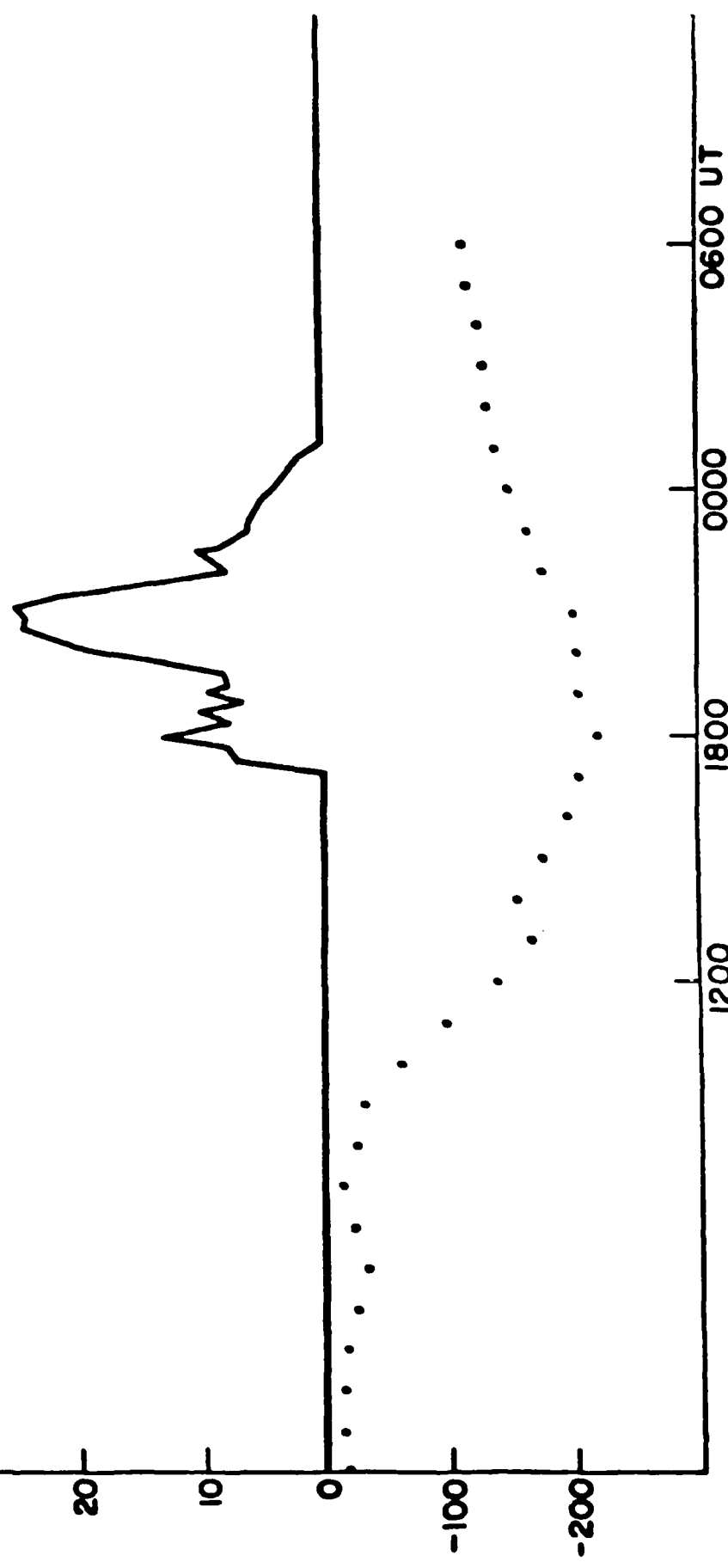
FIGURE 9
EMPIRICAL MODEL OF SCINTILLATION



DEVELOPMENT AND EVALUATION OF
EMPIRICAL MODEL OF SCINTILLATION
ACTIVITY AT 250 MHZ AT
MAGNETIC EQUATOR

MANILA MARCH 5, 1981

SCINTILLATION / DB



$D_{\text{ir}} / \text{nT}$



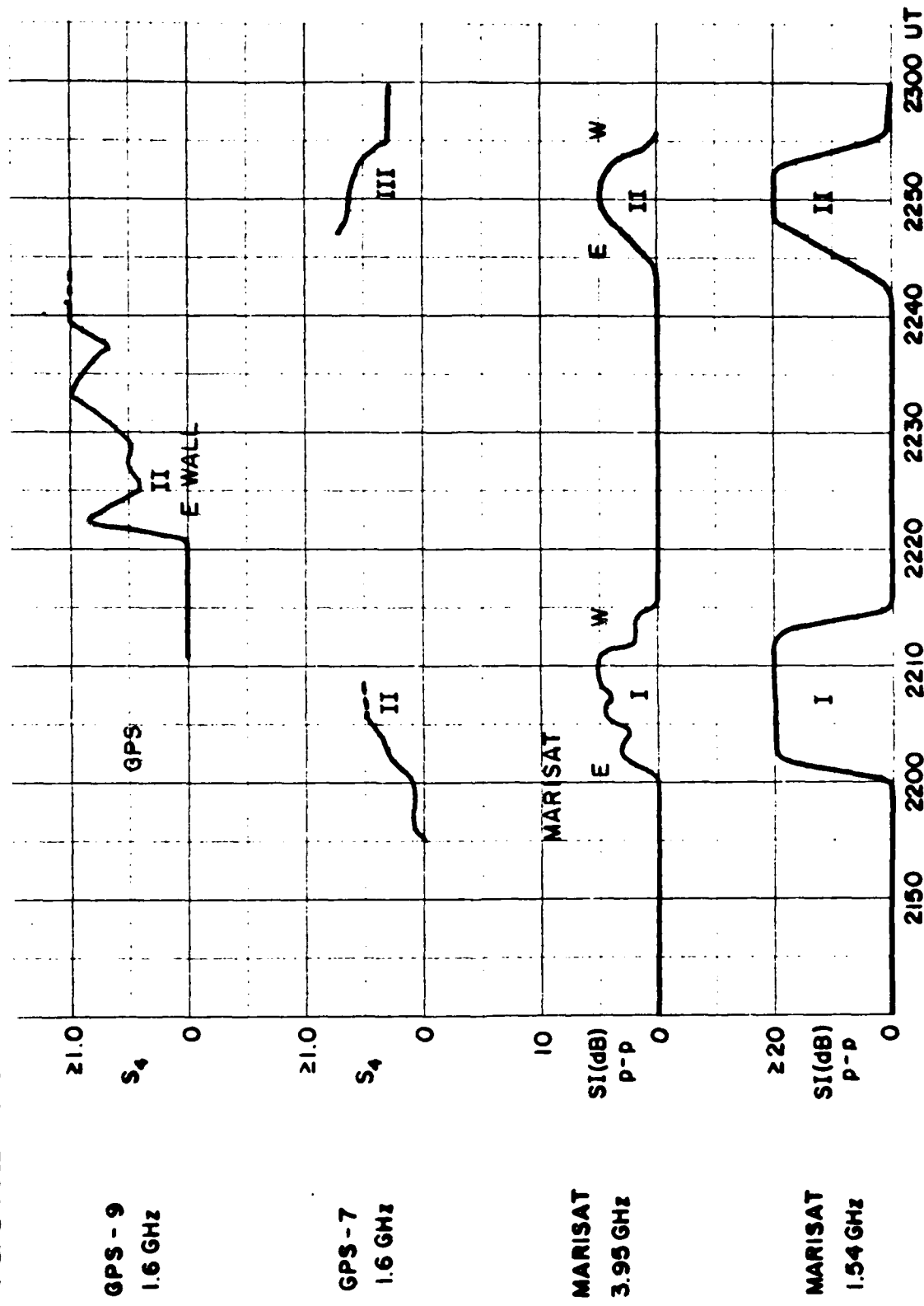
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MAGNETIC TRIGGERING OF IRREGULARITY PATCHES

FIGURE 10

FIGURE 11

SCINTILLATION INDICES - FEB. 4, 1981



SCINTILLATION LEVELS AT WALLS OF PATCHES
OBSERVED FROM ANOMALY LATITUDE

AIRGLOW IMAGING OF PLASMA DEPLETIONS AT THE EQUATOR

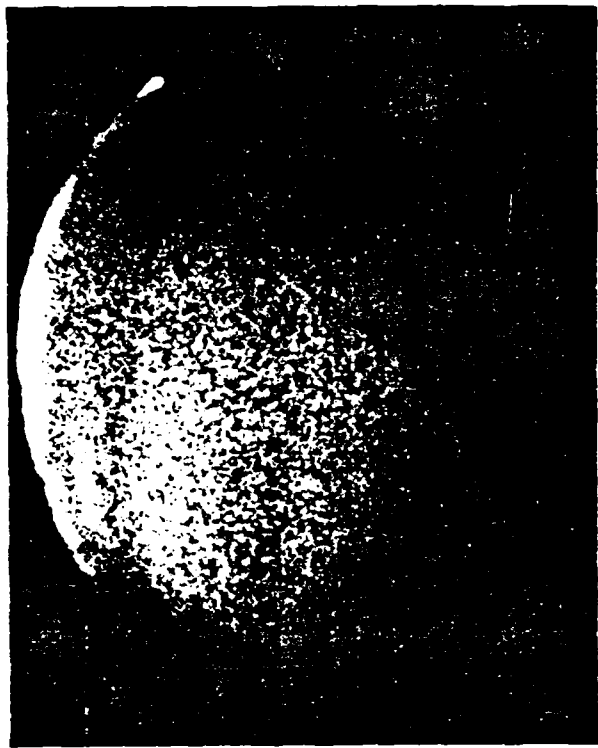


12 September 1982

Natal, Brazil

6300 Å - 16 sec. exposure

21:55 UT (~19:35 LT)



12 September 1982

Natal, Brazil

7774 Å - 16 sec. exposure

21:54 UT (~19:34 LT)

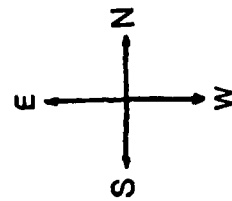
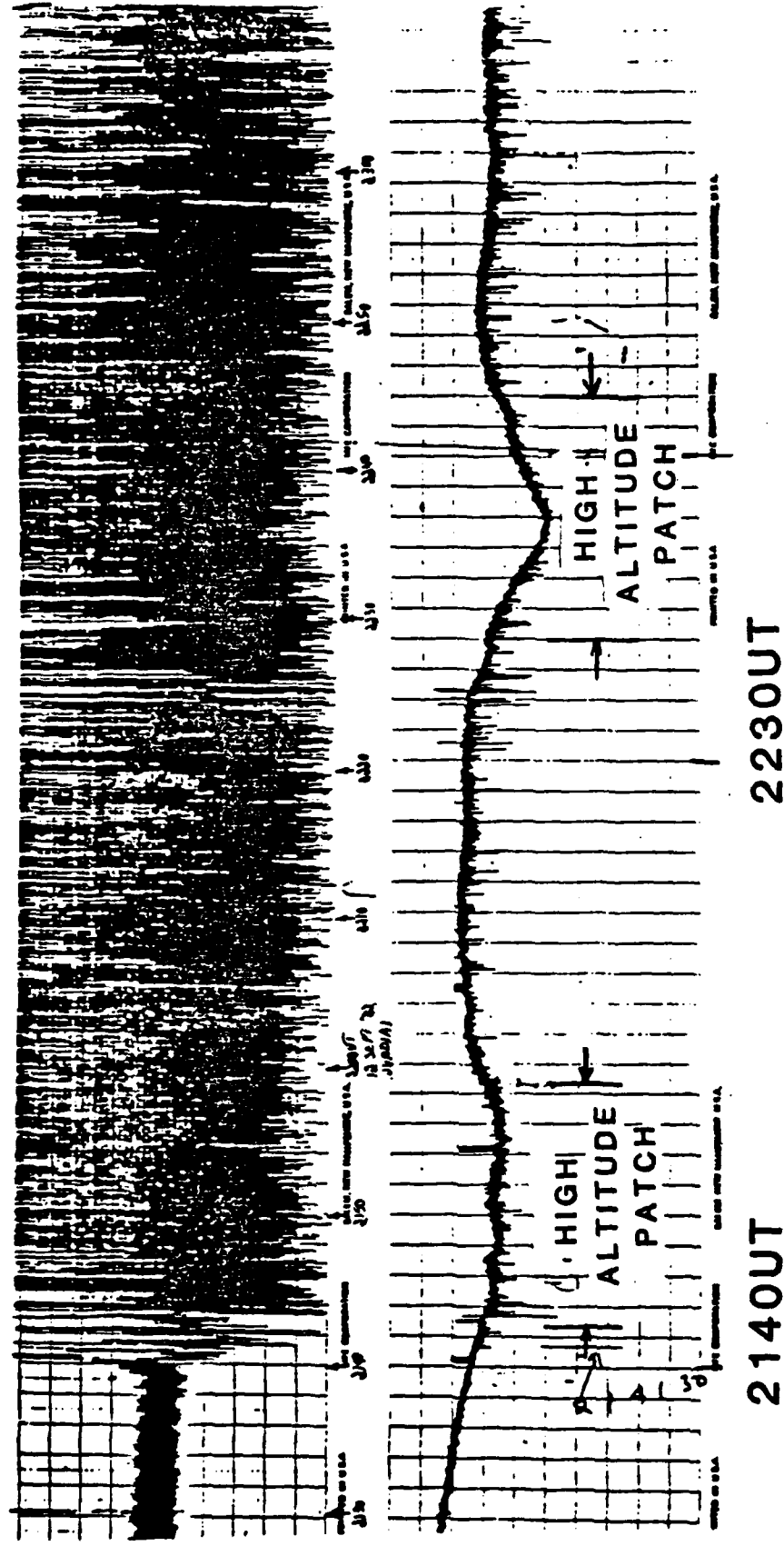


FIGURE 12

FIGURE 13

NATAL, BRAZIL



SCINTILLATIONS AT 137 MHZ (TOP)
AND TOTAL ELECTRON CONTENT DEPLETIONS (BOTTOM)

NATAL PHOTOMETER AND POLARIMETER OBSERVATIONS OF DEPLETIONS

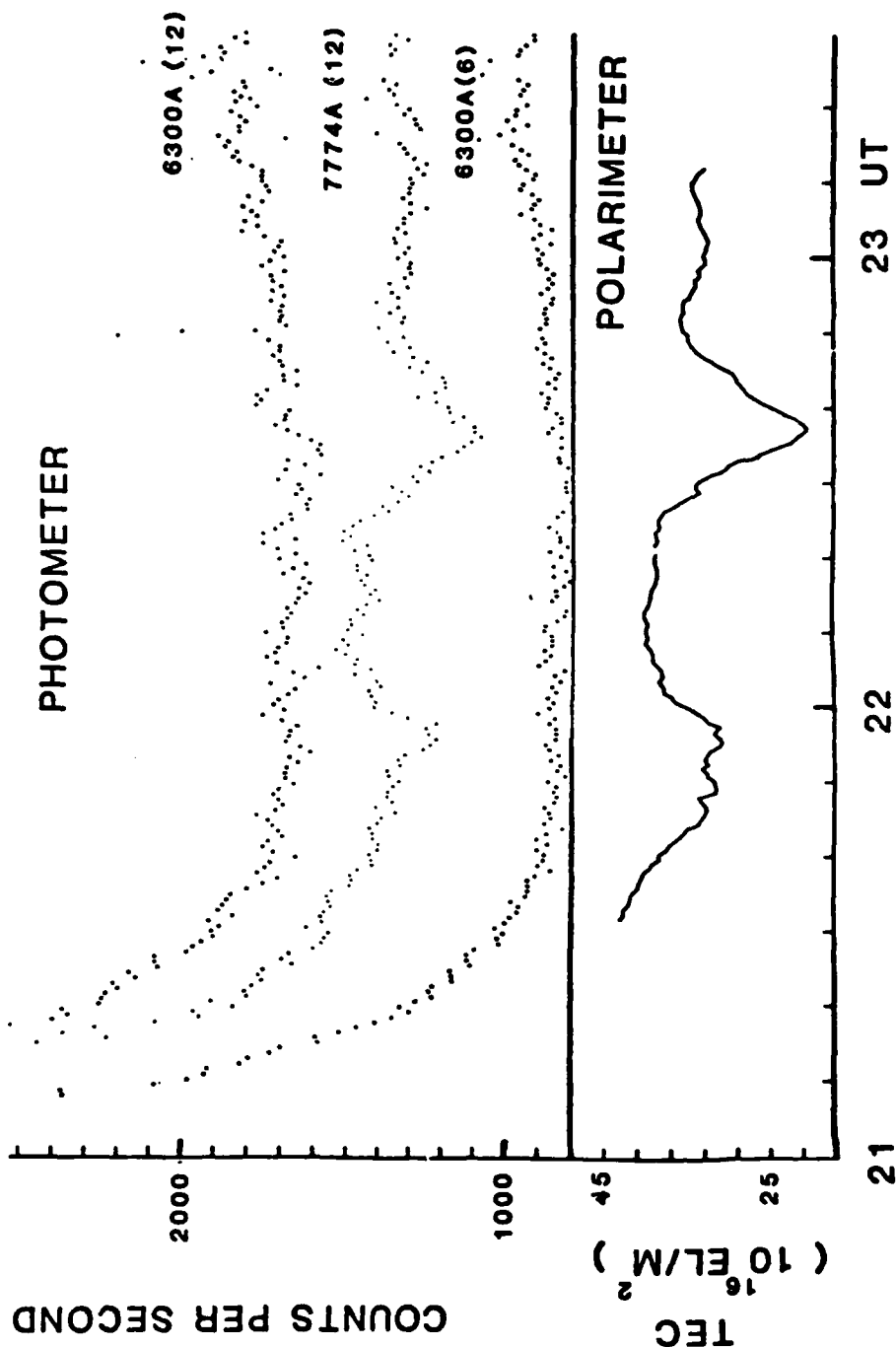
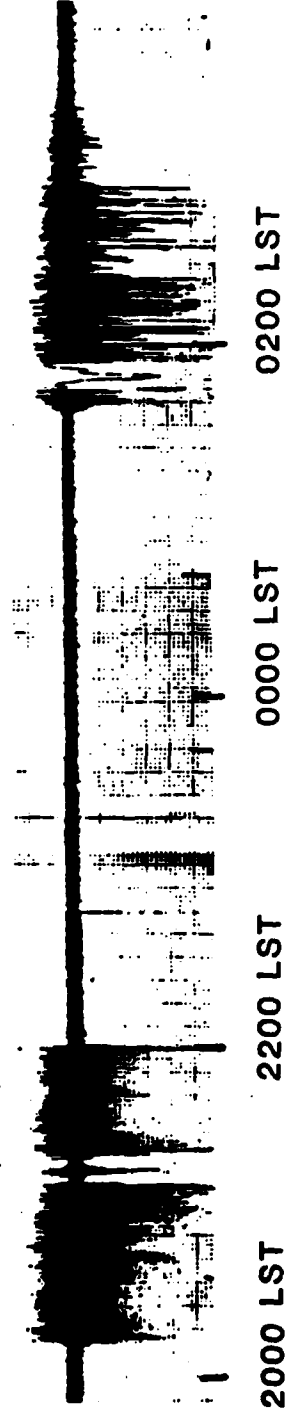


FIGURE 14

FIGURE 15



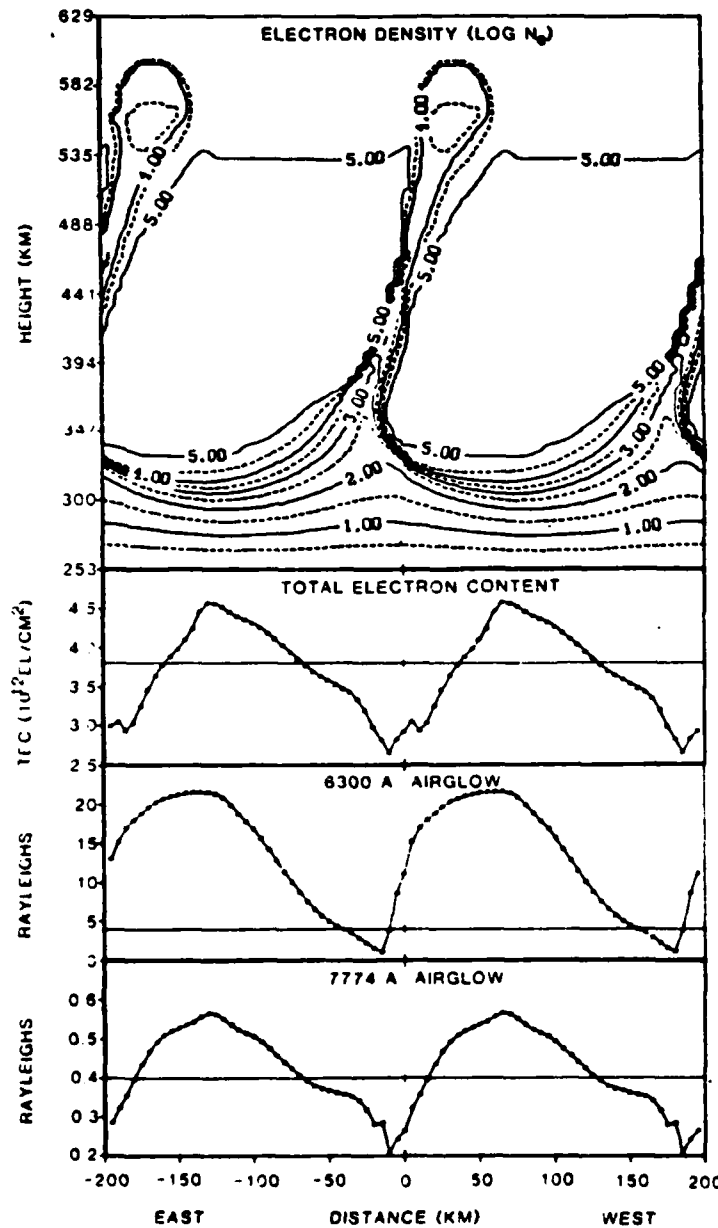
USNS HAYES RECORDINGS OF FLTSAT (23°W)

POSITION 13.2°S 20.4°W

AT 0000 UT MAR 16, 1981

FIGURE 16

PLASMA DEPLETION AIRGLOW CHARACTERISTICS



NRL PLASMA
INSTABILITY MODEL

(Zalesak et al., 1982)

Used to predict
Ionospheric Electron Content
and Airglow Signature of
Equatorial Plasma Depletions.

Confirmed during an
all-sky imaging campaign
in Natal, Brazil.

(Mendillo, Spence, and
Zalesak, 1985)

ELECTRON DENSITY and AIRGLOW EMISSION PROFILES

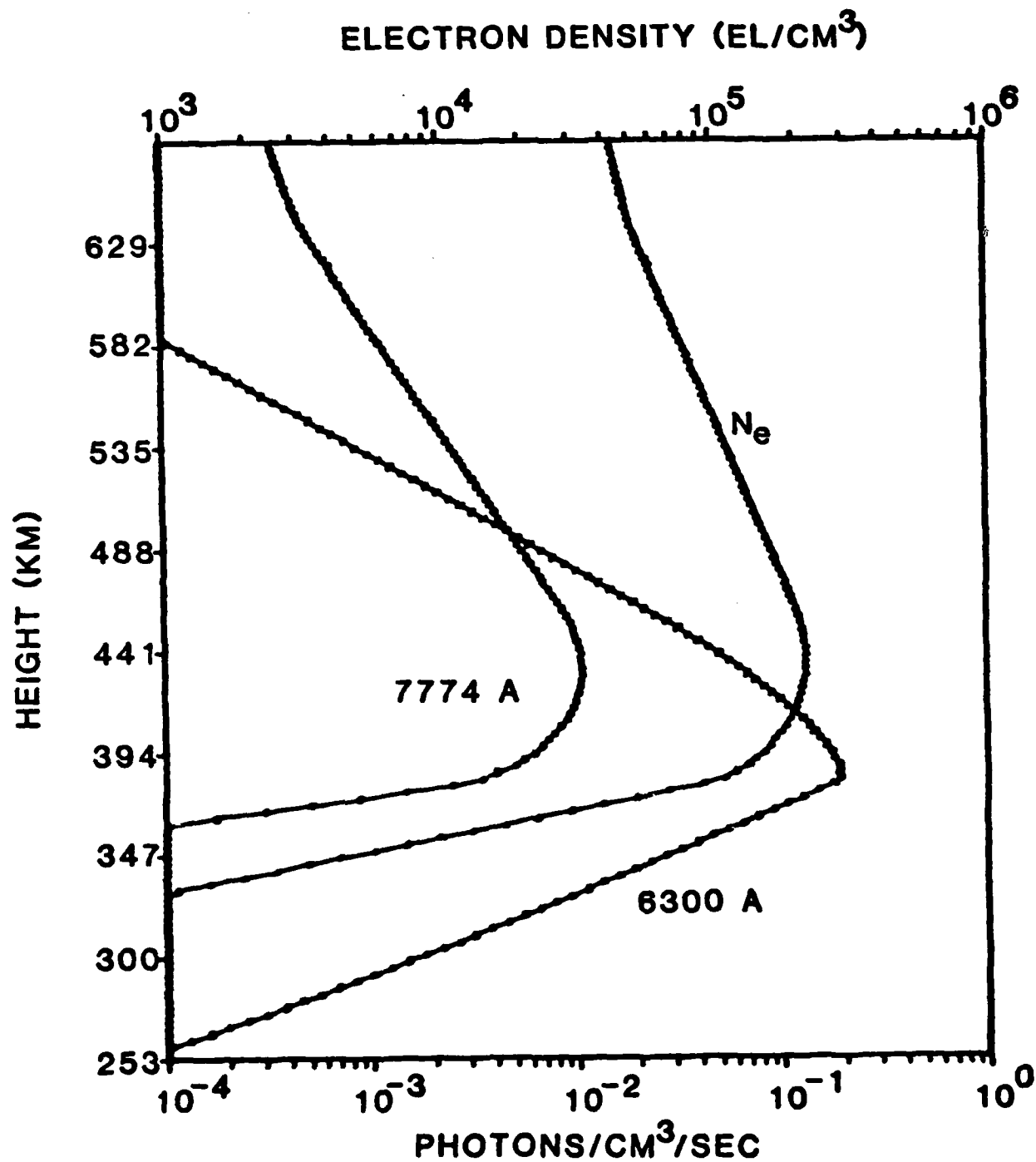


Figure 17 - The initial electron density profile used by Zalesak et al. (1982) for equatorial depletion simulations, together with corresponding airglow emission profiles at 6300 A and 7774 A. The integrated profiles yield 19×10^{12} el/cm² for the total electron content and 4 R at 6300 A and 0.4 R at 7774 A.

VI. PUBLICATION SUMMARY OF BOSTON UNIVERSITY PERSONNEL SUPPORTED BY CONTRACT

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